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Review Article

Do alien species matter? Impacts of invasions in Indian freshwater systems and challenges in management

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Abstract: Alongside anthropogenic activities and habitat destruction, invasions are regarded as one of the most influential components of global change. India as a growing economy and rapidly developing nation has been constantly engaged in infrastructure development which consequently has led to depletion of natural resources and declining quality of habitats aquatic systems in particular. Invasions that have established from the introductions in past during the colonial era and recently spread species are great challenges that hamper survival of aquatic resources. As of 2015, 20 plants, one mollusc and 38 fishes are known to have naturalized in the Indian water bodies. Awareness on the invasive species along with detailed information on the ecosystem-wide impacts is essential for management.

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Introduction

Biological invasions are increasingly recognized as a primary threat to global biodiversity (Wilcove et al., 1998; Bax et al., 2001). Invasive species are widely distributed in all kinds of ecosystems throughout the world, that include all categories of living organisms such as plants and animals, as competitors, predators, pathogens and parasites (Dey, 2011). The spread of exotic species to regions without previous history of distribution is not a new phenomenon. This process has been happening naturally and there are enough evidences from the past that show organisms occupying new territories by crossing barriers. Such invasions however, occurred at a very slow rate but presently the human activities have accelerated this movement. Given the pre-adaptive ability of exotic species, the chances are always higher for them occupying the ecosystems which are constantly prone to habitat alterations as a result of urbanization and other man induced changes (Dudgeon, 2002).

Success of invasion relies on the opportunity that leads the invader to a newer environment. International trade, travel, and transport are the major drivers of biological invasion (McNeely et al., 2001). Some species that become invasive are intentionally imported, and those that escape from captivity are carelessly released into the environment. Accidental transports of invasive species are favoured through crates and containers (carriers of snails, slugs, molluscs, beetles) and military cargo. Despite good intentions, developed countries occasionally facilitate the introduction of invasive species to other countries through development assistance programmes, military operations, famine relief projects and international financing (Pallewatta et al., 2003). Over the last few decades, technological advances have greatly increased the speed of transportation and stimulated by the expansion of the global transport of goods and people, the numbers and costs of invasive species are rising at an alarming rate (NISC, 2001).

Next to habitat loss and fragmentation, invasive species are currently the second greatest threat to biodiversity and aquatic systems. Introduced species, freshwater fish in particular, are reported to thrive in degraded aquatic habitats in many areas of the world (Kennard et al., 2005). Invasives are thus the major

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focus of international conservation concern and the subject of cooperative international efforts, such as the Global Invasive Species Programme (GISP). However, the management and control of invasive species is one of the biggest challenges in conservation. The IUCN guidelines on invasive alien species specifically emphasizes the following: (I) improving understanding and awareness, (II) strengthening the management response (including prevention, eradication and control, (III) providing appropriate legal and institutional mechanisms and (IV) enhancing knowledge and research efforts (IUCN, 2000). Of the many problems is the limited understanding of consistent and predictable impacts of non-native species on native diversity. The complex interactions of invasive species with native ecosystems make invasion ecology an interesting and important area of research. Despite the growing worldwide awareness of alien species invasions, India still lacks specific legislation to regulate the introductions of potentially invasive species into the country (Hiremath and Sundaram, 2013). This review assesses the current knowledge of impacts of exotic species on aquatic systems with management strategy for effective management of invasives. List of species introduced either accidentally or deliberately occupying aquatic habitats in the Indian subcontinent is provided.

Invasiveness and invasion success: A complete knowledge of the invasive species, traits and the distribution is essential prior to developing priorities for control. Not all non-natives become 'invasive'. Some fail to thrive in their new environment and die off naturally. Others survive, but without destroying or replacing native species, it is on this basis some ecologists decry that the term "invasive" is severely overused. However, exotics that do not affect residing species have appreciable effects on their new ecosystems, many exert significant ecological, evolutionary, and economic impacts. Invasiveness is the most important trait in the invaders that makes it sustain against all odds. The role of other qualities put together would eventually lead to establishment. Biological characteristics most often cited as associated with successful invasions are abundance and wide distribution in the native region, high physiological tolerance, genetic traits, r-Selected reproductive strategy, generalist diet or habitat, rapid dispersal and invasion site characteristics (Moyle and Marchetti, 2006). First of all they are pre-adapted to harsh environments with ability to tolerate wide range of fluctuations in ecological parameters such as temperature, salinity, pollution etc., They are aggressive and out-compete native species and further in newer environments they are safe from natural predators and parasites. Invasives also go through rapid genetic change due to newer environments. Yet another notable trait as observed through various studies is the 'invasion meltdown' by which they facilitate the colonization and success of other exotics.

A successful invasion happens when an invader's symbiotic traits, biological characteristics, and invasion site (at multiple scales) are all favourable (Moyle and Marchetti, 2006). Establishment of invasive species normally occurs in 3 stages (Fig. 1). The dispersal is the first step to ensue which may be either in a weak/disturbed system when there are no other species or in a vacant niche when some species already exists. The second step is colonization, it includes all events related to improving a self-sustaining population much enough to invade nearby region. The last step is the succession stage where the new colony starts encroaching the surrounding areas the process during which the habitat space is fully gradually occupied. A successful invader eventually naturalizes and responds to local environmental conditions and to other members of the biotic community in ways apparently indistinguishable from those of native species (Moyle and Marchetti, 2006). The arrival of an exotic species with a high likelihood of becoming a significant invasive species should be regarded serious and prompted for urgent action, because this is the stage at which eradication is both feasible and easy to justify economically. Of the known anthropogenic disturbances habitat degradation and pollution have triggered the invasion. At the same time there are also reports that show successful establishment of exotic species may not be

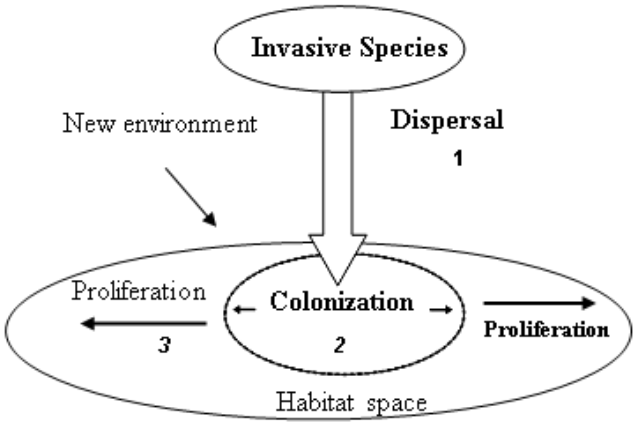

Figure 1. Establishment of invasive species.

due to a single factor but could depend on multiple factor like e.g. complex interactions between the species and the target species (Alpert et al., 2000).

Potential impacts of aquatic invasive species: Species composition of a particular habitat is characterized by the environmental factors that govern it. The establishment of self-sustaining populations of alien species impact native communities at various levels and can alter fundamental ecological properties of the host ecosystems, even to the extent of diminishing ecosystem services (Vincenzi et al., 2011). That invaders, through various activities, affect biodiversity leading to impaired ecosystems is well established (Fig. 2). It is concerning to learn the fact that the impact of invasives on biodiversity is obviously greatest in the protected areas that are relatively undisturbed, which shows that habitat protection alone does not assure safer range for native biota (Scott and Helfman, 2001). Further, the total impact of the invasive species on an ecosystem may be more than what we expect it would cause to the system where it is introduced, since the effect is actually the result of a combination of direct and indirect species impacts (Gutiérrez et al., 2013). Hence interactions between invasive species impacts and other anthropogenic influences can co-occur with possible factors like habitat degradation; other invasive species, pollution, altered climate, hydrology, or fire regimes (Strayer, 2010; Gutiérrez et al., 2013). Aquatic ecosystems are more vulnerable than terrestrial systems in that they are the final recipient of variety of pollutants through multiple processes across a hierarchy of spatial and temporal scales (Paukert et al., 2011). As the reason intact freshwater systems are becoming increasingly rare and many require protection from a range of threats (Abell et al., 2007).

Invasive species are notorious for the impact they cause to the native organisms and the ecosystems. They are deemed as obnoxious for it out-competes native species for resources such as nutrient, light, physical space, and water. Other well-known alterations they could directly or indirectly cause to the system include increased soil erosion, increased incidence of flooding in some situation, increased water use, reduction in water table, changes in soil chemistry, e.g., salt accumulation and loss in productivity. Invasive alien species are as equally ancient as human civilization, and are ongoing chronologically indistinguishable by man. Of late, biological invasions are among the major global issues of concern. Lack of information related to introductions and their current distribution impedes management. Though we know that invasives are capable of displacing, predating native species besides their ability to spread disease and alter habitats, a complete knowledge about the extent and variety of impacts in different regions worldwide is not available. As climate change is crucial in the future of the distribution of invasive species worldwide, it becomes essential to have data of current status of distribution and the dispersal rates (Fig. 2). It would also be relevant on the basis that they are adaptive with broad environmental tolerances, short generation times and high rates of dispersal (Hellmann et al., 2008).

Indian aquatic systems and species introductions: Indian peninsula occupies a strategic position in southern Asia, across the seas to Arabia and Africa on the west and to Myanmar, Malaysia and the Indonesian Archipelago on the east. The river systems in India support one of the richest fish germplasm resources (ca. 840 species) in the world including many rare and endemic species (Vass et al., 2009, Singh and Lakra, 2011). Aquatic systems and water in

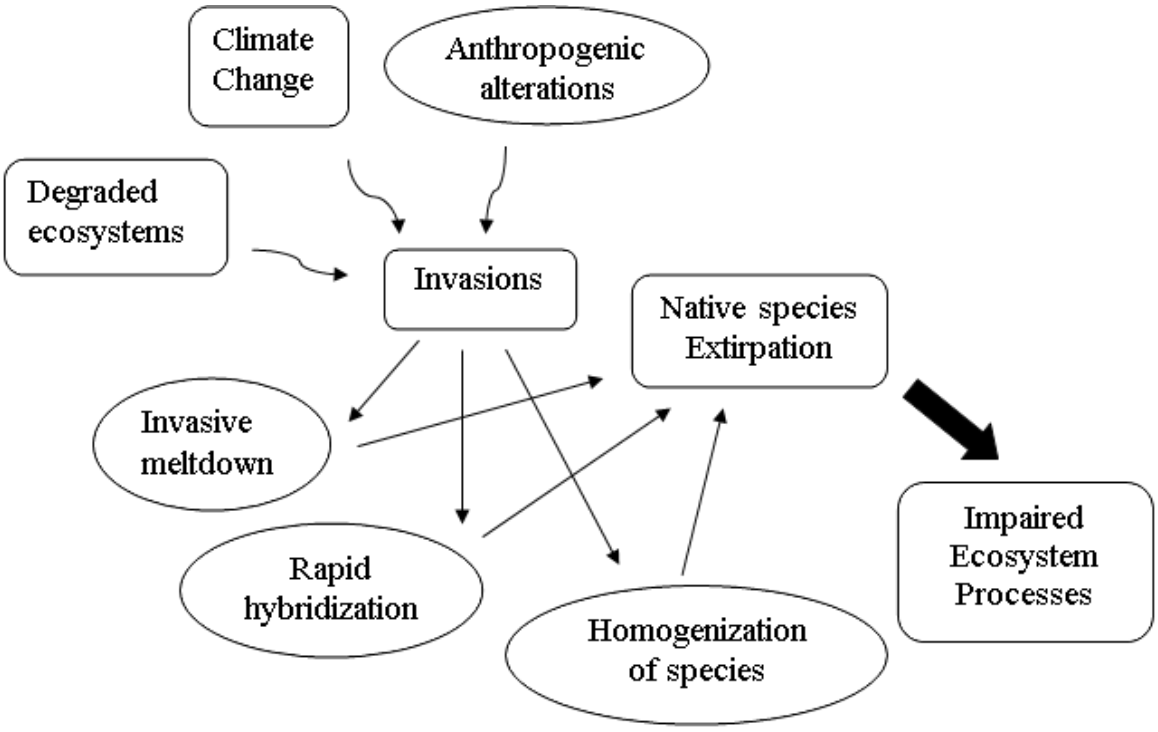

Figure 2. Impact of exotics on species and ecosystems.

India are intricately intertwined with the cultural fabric of the country, and has both economic and social connotations (Dudgeon, 1992; UNICEF, 2013). The total water potential of India, determined by mean annual river flows, is estimated to be 1,672,590 million m^3. However, this could possibly not be sufficient to meet the needs of world's second most populous country. As the reason several crucial issues prevail over the water sector in India notable of them are erratic distribution of rainfall, water use inefficiency; unregulated groundwater extraction; inter-state river disputes and growing financial crunch for management of resources. Lack of relevant awareness on sustainable utilization in the part of citizens and the failure of decision makers to enforce stringent rules towards reckless activities leading to declining aquatic resources have made problems complex. The alterations in aquatic biogeochemistry and ecosystems are expected to have a profound impact on water quality and living resources. Aquatic systems in the current state would only facilitate the establishment of invasive species (Muralidaran et al., 2015).

Introduction of certain exotic species are said to have been deliberate during the pre-independent period and more prevalent during the colonial era to gratify the then rulers of their aesthetic interest (McNeely, 2001). The present day invasions in Indian inland waters both of floral and faunal components could be attributed to the increasing dependence on aquaculture and flourishing aquarium trade. Species from temperate and tropical regions of aquacultural and commercial value are being imported on regular basis that threaten native biodiversity (Muralidharan et al., 2015). Activities linked to such industries could be held responsible for the estimated occurrence of 300 alien fish species in India (Singh and Lakra, 2011). This practice could not be completely restricted given the revenue it yields in addition to the employment opportunities available for youth forming a considerable proportion of the total population at present.

Eradication of invasive and obnoxious species is globally accepted practice and has been adopted as a key management option in extenuating the impacts of biological invasions (Genovesi and Shine, 2003; Genovesi, 2005). Though invasion impacts had been experimentally quantified for non-native species, in all major freshwater and marine habitats, most are from the regions occupying temperate latitudes

(Thomsen et al., 2014). In India, regulation of introduction of invasive alien species and their management has been covered by the National biodiversity action plan, in the absence of exclusive policy. NBFGR (National Bureau of Fish Genetic Resources) evaluated the impact of invasive fishes in India and a strategic plan for quarantine and exotic fish introductions has been prepared. Action plans developed for non-native species management in India initiated under Asia-Pacific invasive species Network, a cooperative alliance of 32 member countries, share information on the invasive species. Despite the well-established quarantine system, which regulates the import and export of biological materials to check the entry of the undesirable species, there are registered cases of alien introductions (Tripathi, 2015; Bijukumar et al., 2015). Studies on the impact of invasive species in Indian waters are relatively poor as compared to other nations. Species that have invaded the aquatic systems are not completely ascertained, however a provisional list of species based on literature their impacts on native community and habitats shows the occurrence of 20 plants, 1 mollusc and 38 fishes (Appendix 1). Most of the fish species were deliberately introduced, to augment aquaculture activities considering the social and economic importance of the fishery (Ghosh et al., 2003; Katiha et al., 2005; Singh and Lakra, 2011; Singh et al., 2014).

Challenges: Impact of invasions on the aquatic systems, as for as India, has not been perceived as a major issue however is likely to emerge as a serious problem because, the severity of the invasions on resources is not felt as of now. Globalization has been the prevalent economic ideology, with prime objective of urbanization and infrastructure development which could seriously impact on the ecology of freshwater systems. Carried by the marvels of urban growth we would have failed to realize the increasing thrust on the pristine habitats that harbor native diversity. Also many alien invasives benefit from the reduced competition that follows habitat degradation. Management plans to control invasions would not be effective when the level of awareness is inadequate to check the introduction and spread. Hence understanding the factors related to invader abundance and impact is essential also the conservation measures have to be prioritized corresponding to the cause and the impact (Kulhanek et al., 2011; Tripathi, 2015).

Homogenization is a threat to indigenous species; it is commonly asserted that exotic species promote the homogenization of biological communities by influencing community composition (Nentwig, 2007). Freshwater fish fauna that are highly differentiated and isolated lose their uniqueness resulting in the loss of local and regional distinctiveness. Introduction of exotic freshwater fishes, which is common worldwide mainly for aquaculture, is especially harmful in terms of biodiversity. Even transfer of species from a different river system which already inhabits related congener could tremendously impact the system and the residential species. The morphological distinction of few species is completely chaotic and a very classic example of such a species, influenced by the impact of cultivable transferal species is the fish *Labeo* most popular in inland aquaculture. This genus due to inbreeding and other reasons has become enigmatic with number of species with similar morphological features difficult to distinguish. Invasives spread through pet trade are even worser with their hybrid origin, as the case of the armoured Suckermouth cat fish *Pterygoplichthys* exhibiting “hybrid superiority” through successive invasions (Nico et al., 2012; Bijukumar et al., 2015).

Interactions of the invasives with the native organisms after establishing in newer environments have modified and evolved significantly. Non-indigenous species with morphological similarity to native residential species failed to establish due to the non-availability of niche space (Azzurro et al., 2014). However there are contradictory findings against the widely popular hypothesis in invasion biology that species-rich communities are more resistant to invasion than species-poor communities. As expected the native communities are supposed to restrict and control the rate of invasion however, the rate of invasions will actually increase with time, because the disruption of native species promotes further

invasions as some invaders are facilitative rather than being invasive (Rooney et al. 2007). For example the invading dreissenid mussels by the provision of food in the form of fecal deposits favour further invaders such as the amphipod *Echinogammarus ischnus* (Ricciardi, 2001). *Oreochromis mossambica* got introduced into tanks along with other fish fry during the transfer of commercial fish seeds from aquaculture farms. They are observed to co-exist with other residential native species.

Exotic species are known for their adaptive traits and in course of their evolution have developed strategies by sharing habitat and resources mutually with local residential species, which is referred as 'Invasive meltdown'. Invasion of *Eiccornia crassipes* (Water hyacinth) due to eutrophication challenges the life supporting ability of aquatic systems remains the world's most problematic water weed. Purple Swamphen (*Porphyrio porphyrio*) a water bird that usually nests in mass of floating debris or amongst matted reeds slightly above water level utilizes invasive water hyacinth foliage in the absence of native fauna, it is also said to facilitate the proliferation of the weed.

Prosopis juliflora (Mesquite) native to Mexico, South America was introduced to India. However, it is a case of turn-about as it has been used as fodder for goat and other cattle and it also supports village dwellers for fuel and production of charcoal for industry. This species is hard and expensive to remove as the plant can regenerate from the roots. This is interesting case along similar lines is the alewife, a non-native fish that was first reported in the Great Lakes in 1873 which was considered a costly nuisance species in the mid-20th century. Now it is considered a valuable (but still exotic) food source for salmon and lake trout, which supports billion dollars' worth sport fishery. Aquaculture is one of the fastest growing areas of food production that sustains the growing population by food and economy which has been the known sector to establish exotics in newer regions. As the reason the popularity and admiration gained by an exotic species is greater than the knowledge required to realize the long-term impacts it would cause. Interestingly none of the invasive species has been declared as prohibited in any state or the country.

Transboundary rivers are ecologically important however are socially prone to dispute owing to problems arising from sharing of water between states. Merger of rivers and construction of navigation canals between rivers develop a network of waterways that open long distance dispersal routes for aquatic species from several bio-geographic areas. This leads to homogenization of species. Past and present governments have insisted in river linking projects by connecting major rivers of Himalayan region to those in the southern part of India. The objective behind such scheme is water supply for irrigation, however with compromise on aquatic organisms. Introduction of species, be it through any mode, either transplanting or translocating is said to be ecologically disastrous to major biodiversity nation like India, with more than 20 geographically distinct drainage basins (Tripathi, 2015). Further changing climate patterns will probably produce significant effects on the biodiversity of freshwater ecosystems throughout the world and possibly initiate varying adaptive responses. Species might survive climate change by shifting their distributions or through evolution and become adapted to the new local climatic conditions. As the invasives are tolerant and capable of surviving in the harsh environments the spread of invasions are only facilitated by climate variations. Removal of certain invasive species needs fundamental knowledge of population ecology which is lacking for many exotics. Further control of parasitic infections in introduced culture species is another challenge as it could be spread to native forms (Shomorendra et al., 2005; Dash et al., 2008). The successful eradication of the parasites in aquaculture stations would be possible only after knowing the population biology sufficiently (Kaur et al., 2012b). Measures based on biological and chemical control are not sometimes advisable, which could have harmful impact on other native species and the habitat as a whole. Implementation of similar such projects in India with objective of combating the impact of non-native species should be undertaken after due considerations related to safety aspects of the

environment as well as people.

Management and control strategies

Though, invasive species are considered as ecological threat throughout the world, the management methods adapted to control are not the same. However, certain aspects in general are applicable worldwide.

Careless behaviour leads to unintentional introductions: Avoid using known invasive species. Creating awareness among people would enable them to make informed choices among pets/ornamental species.

Reducing activities that alter landscape: Invasive species thrive well in disturbed systems where the native community has been displaced. Protection of healthy native species is the key to control invasive species.

Regular monitoring and assessment: All land use plans need to be monitored regularly and invasive species need to be checked for their removal. Scouting at regular interval helps in preventing spread of invasive species. Removal of invasive species when the population is low helps native species to occupy the empty niche.

Community awareness and perceptions: Exotic species attract a range of opinion in country like India, based partly in terms of ecological impact but more on the human utility. Promoting community participation through awareness and voluntary involvement in efforts to eradicate invasive species could well yield better results.

Development of database for species distribution: Building species distribution database for the invasive alien species using spatial stochastic model with provisions for updation through region and species specific surveillance programme.

Adoption and applicability of control strategy: Choosing the most appropriate control strategy is important. Proper guidance is required in the choice of control measures. Hence it is necessary to have rigorous comparisons of control success under field conditions to have a robust decision support tool.

Coordinating committee to control invasion: Establish a coordinating committee consisting of members from various agencies preferably agriculture, irrigation, engineering, fisheries, environment and industry

Conclusion

Despite the growing concern for the impact of invasive species, exotics are constantly released as we have not completely halted activities promoting such introductions. The biology of invasive species and lack of site specific information on its ecology are major bottlenecks in developing effective tools for its management. As ecologists opine conservation of biodiversity needs good scientific information to inform our decisions on advocacy, public awareness-raising, and support to field and policy projects. Conservation of indigenous species from the impact of invasive aliens could be successful through the following steps: (i) gathering complete information on the species and the ecosystem wide impact, (ii) innovative control and eradication methods developed after incorporating techniques found effective in successful invasive management projects and (iii) proper and periodic monitoring of restored sites to control against future invasions. Strategies in effective management of the invaders are to be modified and developed in the rapidly changing trends of the climate.

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Appendix 1. List of invasive species reported from Indian waters (based on literature).

	Organism/Species	Native region	Impact on invaded system	Literature
	Plants			
1	*Alternanthera philoxeroides* Herb	South America	Infesting rivers, lakes, ponds and irrigation canals	Julien et al. (1995); Pramod et al. (2008); Devi and Sharma (2010); Masoodi and Khan (2012)
2	*Acacia nilotica* Tree	Australia	Replaces native non-tree vegetation, such as grassland and shrubland	Pandey et al. (1999); Bargali and Bargali (2009)
3	*Cabomba caroliniana*	Brazil	Clogs drainage canals and freshwater streams	Orgaard (1991); Matthews et al. (2013)
4	*Eupatorium cannabinum* L. herb	British Isles	Alter soil nutrients and hydrology potentially reducing the suitability of the area to native flora	ISSG (2011)
5	*Eichhornia crassipes* (Mart.) Solms Free floating weed	South America	Impedes flow and clogs	Patel (2012)
6	*Gymnocoronis spilanthoides*	South America	Rapidly cover water bodies with a floating mat, excluding other plants and the animals that rely on them	Kumar (2009)
7	*Ipomoea cornea*	Brazil	Disrupts succession and decreasing biodiversity	Cook (1987); Chaudhuri et al. (1994); Chandrasekar (2012)
8	*Limnocharis flava* (L.) (Buchenau, 1903)	America	Serious weed in rice fields, irrigation canals and wetlands	Abhilash et al. (2008)
9	*Ludwigia peruviana* (L.) Hara	South America	Vigorously opportunistic, clogging waterways	Chowdhury et al. (2013)
10	*Lantana camara* L.	Central and northern South America and the Caribbean	Disrupts succession and decreasing biodiversity	Sharma et al. (2005); Sahu and Singh, (2008); Priyanka and Joshi (2013)
11	*Melaleuca quinquenervia* (Cav.) Blake	Queensland and New South Wales, Australia	Alters soil chemistry and modifies Everglades ecosystem processes	Orwa et al. (2009)
12	*Mikania micrantha* (L.) Kunth.	Central and South America	Damages or kills other plants by cutting out the light and smothering them	Choudhury (1972); Muniappan and Viraktamath (1993); Ramachandran and Soosairaj (2008)
13	*Paspalum vaginatum* Sw.	North America	Impact on fauna communities	Xie et al. (2009)
14	*Phalaris arundinacea* L.	Europe Asia and North America	Forms dense and impenetrable mats of vegetation	Holm et al.(1991)
15	*Prosopis* spp. *P. juliflora* and *P. pallida*	Mexico, South America and the Caribbean.	Smother native vegetation hard and expensive to remove as the plant can regenerate from the roots	Orwa et al. (2009); Kaur et al. (2012a)
16	*Rubus moluccanus* Linnaeus	Malaysia to Australia, Solomon Islands, New Caledonia and Fiji	threatens native plants	ISSG (2011)
17	*Salvinia molesta*	southeastern Brazil and northern Argentina	Form dense vegetation mats that reduces water-flow and lowers light and oxygen levels in the water	Kumar et al. (2005)
18	*Spartina alterniflora* Loisel.	North and South America	negative effect on native species including some endangered	ISSG (2011)
19	*Triadica sebifera* (L.)	China and Japan	Aggressively displaces native plants and forms monospecific stands	Jaryan et al. (2007)
20	*Ulex europaeus* L.	Europe and Great Britain and Ireland	Displacing cultivated and native plants	Richardson and Hill (1998)
	Mollusc			
21	*Achatina fulica* Bowdich, 1822	East Africa	Severe damage in infested plants, Transmission of parasites	Raut and Barker (2002)

Appendix 1. Continue.

	Organism/Species	Native region	Impact on invaded system	Literature
	Fishes			
22	*Amphilophus trimaculatum* Gunther	South America	Predation	Knight (2010)
23	*Aristichthys nobilis** Richardson 1845	Southern China	Endangers native species	Singh and Lakra (2011)
24	*Carassius auratus* (Linnaeus, 1758)	Central Asia	Increasing turbidity, predation upon native fish, and helping to facilitate algal blooms	Rema Devi (1987); Knight (2010)
25	*Cichlasoma trimaculatum* Gunther 1867	El Salvador, Honduras, Nicaragua	Highly Aggressive	Knight (2010)
26	*Clarias gariepinus* (Burchell, 1822)	Africa	Threat to endemic aquatic fish, particularly in South Africa and India	Mishra et al. (2000); Gopi and Radakrishnan (2002); Krishnakumar et al. (2011); Sarkar et al. (2012)
27	*Ctenopharyngodon idella* (Valenciennes in Cuvier and Valenciennes, 1844)	China and Russia	Eliminate spawning substrate, disturb sediment and muddy waters, reduce water quality, increase nutrients in waters accelerating eutrophication, decrease oxygen levels, and promote alagal bloom.	Fishbase (2004); Sarkar et al. (2012)
28	*Cyprinus carpio communis* Linnaeus 1758	Europe in rivers around the Black Sea and the Aegean basin	Increased siltation and bioturbidity damage aquatic macrophytes	Daniels (2006); Krishnakumar et al. (2011); Sarkar et al. (2012)
29	*Cyprinus carpio specularis* Lacepede	South-east Asia	Damage aquatic macrophytes	Krishnakumar et al. (2011); Singh and Lakra, (2011)
30	*Cyprinus carpio* Bloch*	South-east Asia	Compete with native species	Singh and Lakra (2011)
31	*Gambusia affinis* (Baird and Girard, 1853)*	Southern USA and northern Mexico	Extremely aggressive and attack other fish, shredding fins. Host of parasites infecting native fish	Daniels (2006)
32	*Gambusia holbrooki* (Girard 1859)	North America	Predate on amphibian eggs; and predate and compete with tadpoles	Sharma (1994); Nagdali and Gupta (2002)
33	*Hypophthalmichthys molitrix Val.*	Japan, Asia	Compete with native species	Singh and Lakra (2011)
34	*Onchorhynchus mykiss Walbaum*	Europe	Invasive, carries parasite	Singh and Lakra (2011)
35	*Onchorhynchus nerka* Walbaum	North America	Aggressive, impacts habitat	Singh and Lakra (2011)
36	*Oreochromis mossambicus* (Peters, 1852)	Southern Africa	Threat to native species through competition for food and nest space	Sugunan (1995); Lakra et al. (2008); Sarkar et al. (2012)
37	*Oreochromis niloticus* Linn. 1758	Southern Africa	Threat to native species through competition for food and nest space	Bhakta and Bandyopadhyay (2007)
38	*Osphronemus goramy* Lacepede,1801	South east Asia	Resource competition, opportunistic carnivore, carry pathogens	Raj (1916); Chandrasekhar (2004); Raghavan et al. (2008)
39	*Pangasius sutchi* Sauvage, 1878	Africa	Carnivorous- devours Insect, fish fry and fingerlings and tadpoles.	Bhakta and Bandyopadhyay (2007)
40	*Piaractus brachypomus* Cuvier 1818	South America	Opportunistic	Singh and Lakra (2011)
41	*Poecilia reticulate* Peters, 1859	South America	Threat to indigenous fauna	Kharat et al. (2003); Deacon et al. (2011)
42	*Pterygoplichthys anisitsi* Eigenmann & Kennedy, 1900	South America	Alteration of bank structure and erosion, disruption of aquatic food chains	Sinha et al. (2010)
43	*Pterygoplichthys disjunctivus* Weber, 1891	South America	Alteration of bank structure and erosion, disruption of aquatic food chains	Sarkar et al. (2012); Singh (2014)

Appendix 1. Continue.

	Organism/Species	Native region	Impact on invaded system	Literature
44	*Pterygoplichthys multiradiatus* Hancock, 1828	South America	Include alteration of bank structure and erosion, disruption of aquatic food chains, competition with native species, mortality of endangered shore birds, changes in aquatic plants	Hoover et al. (2004); Daniels (2006); Knight (2010)
45	*Pterygoplichthys pardalis* Castelnav, 1855	South America	Alteration of bank structure and erosion, disruption of aquatic food chains, competition with native species,	Knight (2010); Muralidharan et al. (2015)
46	*Puntius gonionotus* Bleeker	South East Asia	Not completely known, however damages aquatic habitats due to its potential in weed control	Singh and Lakra (2011)
47	*Pygocentrus nattereri* Kner, 1855	South America	Predation, threat to native fishes	Knight (2010)
48	*Salvelinus fontinalis* Mitchill 1814*	North America	Compete with native fishes, aquaculture	Singh et al. (2013)
49	*Salmo gairdneri irideus* Ranae	Europe	Compete with native trouts	Singh et al. (2013)
50	*Salmo gairdneri shasta* Ranae	Europe	Compete with native trouts	Singh and Lakra (2011)
51	*Salmo trutta fario* L.*	Great Britain	Not known	Singh and Lakra (2011)
52	*Salmo levensis* Pickens 1928	Great Britain	Yet to establish	Singh and Lakra (2011)
53	*Salvelinus namaycush* Walbaum 1792	Japan	Not known	Singh and Lakra (2011)
54	*Salmo salar* Linnaeus	North America	Impact not established	Singh and Lakra (2011)
55	*Tinca tinca* (Linnaeus, 1758)*	Europe and across Asia to China	concerns over competition with native fish	Jones and Sarojini (1952); Fishbase (2004)
56	*Tilapia zilli* Gervais 1848	South east Asia	Not exactly known	Singh and Lakra (2011)
57	*Trichopodus trichopterus* (Pallas, 1770)	Mekong basin in Cambodia, Laos, Thailand, Vietnam and Yunnan	Resource competition	Daniels and Rajagopal (2004); Daniels (2006); Krishnakumar et al. (2009)
58	*Xiphophorus helleri* Heckel, 1848	South America	Resource competition, aggressive nature	Daniels (2003); Raghavan et al. (2008)
59	*Xiphophorus maculatus* Gunther, 1866	South America	Resource competition, aggressive nature	Kharat et al. (2003); Krishnakumar et al. (2009)

49 & 50 –Synonyms of *Oncorhynchus mykiss* Jordan (according to Fishbase).